# The Effect of the Hemlock Woolly Adelgid, *Adelges tsugae* (Homoptera: Adelgidae) in Natural Hemlock Stands in New Jersey.

## Annual Report 2002

**Hemlock wooly adelgid**


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## INTRODUCTION

This report is the result of the Study Plot monitoring program partially funded by the United States Department of Agriculture - Forest Service and by the New Jersey Department of Environmental Protection - Division of Parks and Forestry. The objective of this work is to show the impact of the hemlock woolly adelgid (HWA) and associated factors in natural hemlock stands over an extended period. Data collected include stand mortality, HWA population level, crown ratings and percent new growth.

## MATERIALS AND METHODS

### Study Plots

Thirteen study plots were set up during the years 1988 to 1990, eleven of which were established in 1988. These plots were chosen as representative of natural hemlock stands and adelgid populations. Of the eleven, nine plots were infested with adelgid and two were uninfested. The same eleven plots were monitored in 1989. Two of the plots were abandoned in 1990 because they were continually being treated with chemicals and/or fertilized and field personnel were unable to get an accurate record of the treatments. In 1990 two plots were added which left eleven plots that have been continuously monitored since 1990. Data was not available from one plot in 1998 because permission to enter the property could not be obtained from the new property owners. Permission was obtained in 1999.

After a plot was chosen as representative of a noninfested, lightly infested, or heavily infested hemlock stand, three subplots were established within each plot to ensure that an undisturbed group of trees could be observed from year to year. Subplots were set up using the following criteria: 1) located in the densest parts of the hemlock stands; 2) good accessibility to branches; 3) open areas of a plot were avoided because they were not representative of a plot as a whole.

A #10 prism was used to delineate the sample hemlock trees within the subplot. One tree was designated as the center tree and any tree that was observed within the 360° radius of the prism was included in the subplot. The tree lying closest to magnetic North with respect to the center tree was designated tree number 1. All hemlock trees within the prism, moving in a clockwise direction, were numbered sequentially.

### New Growth - Foliage

New growth counts were recorded annually using the trees in the three subplots to determine the quality and health of the trees at each site. New growth comes out of the ends of the old branches, with the new growth readily distinguishable from the previous year's growth by the light green color of the new needles and lighter colored stem. These counts were completed from June to August. The procedure was as follows: a branch on a tree was chosen skewed toward the branches showing the most potential for new growth. A twelve-inch (30 cm.) ruler was used to measure one foot of branch starting from the tip and proceeding toward the trunk. All the terminal ends of the shoots, both living and dead, were counted. The number of terminals with new growth was determined and the percent of new growth was calculated by dividing the total number of terminals into the total number with new growth. Ten samples were taken from each subplot, a total of thirty samples per plot. As many different trees were used as possible but if the branches could not be reached or if there were less than 10 trees in the subplot, more than one count was made per tree. If the branches on the subplot trees were inaccessible, counts were made from samples on trees as close as possible to the subplot.

### HWA Population Levels

Previous work (Ward *et. al*. 1992) indicated that the percent new growth in hemlocks declines precipitously when a population of 25 - 30 HWA per 100 needles is reached. There was no appreciable effect on the percentage of new growth when populations of HWA were less than 25 - 30 HWA per 100 needles. The HWA population categories were then assigned as follows with H = heavy, > 30 adelgids per 100 needles; L = light, < 30 adelgids per 100 needles; N = none, no adelgids per 100 needles.

Population levels were determined by sampling HWA infested trees outside of the subplots. Cuttings were made from six different trees within the plot (2 cuttings per subplot), but outside the boundaries of the subplots. These cuttings were brought back to the laboratory and five, 100 needle sections were randomly selected from each of the six cuttings. All adelgids present in the sections were counted and then an average was obtained for each of the plots. Figure 1 shows the HWA on an infested twig.

**Figure 1. Hemlock Woolly Adelgid**

**Crown Rating**

The crown ratings of ratio, transparency and density for all the plots were implemented as in Millers *et. al*. 1992 with the exception of die back and crown diameter. Die back was not included in the crown ratings because the project has been ongoing for some time and there is no way to evaluate that measurement since it is unknown what the crowns were like at the beginning of the project. Crown diameter was felt to be highly variable and thus was not included in the data. Crown ratio is the percentage of total tree height that supports living foliage. Crown density is the amount of foliage, branches *etc.* that blocks light visibility through the crown and is expressed as a percentage. Crown transparency is the amount of visible light going through the live portion of the crown.

**Mortality**

Counting the number of dead trees in a plot and calculating a percentage determined tree mortality. Mortality was defined as no cambial activity and no needles on the tree.

**RESULTS AND DISCUSSION**

**New Growth and HWA Population**

Table 1 shows the percent new growth and population level within the plots.

Generally there is a series of years when the trees put out more new growth as long as the HWA population is light but as soon as the population becomes heavy, the amount of new growth declines except at the beginning of a heavy infestation. The trees become stressed and as the health of the tree declines less new growth is available and the HWA population declines. The trees are able to recover a bit and produce more new growth due to the lower HWA populations but after a year or two of recovery there is sufficient new growth for the HWA to come back at high population levels and stress the trees once again. This is expected since the HWA prefers new foliage and is rarely found on older material. After several years of heavy infestation the amount of new growth declines substantially (McClure *et. al* . 1996). There are exceptions to this depending on the environmental conditions at the site.

Onken (1994) found that there was a relationship between the amount of rainfall that a stand received the previous year and the amount of new growth that a stand put out the following year. If the previous year was wet, then the trees put out a greater amount of new growth the following year. Weather and the amount of water available then also affect the health of the tree.

Water seems to play a major role in the amount of new growth and the survivability of the trees. In the plots with high tree mortality field personnel have observed that the trees located at the bottom of a hill, at the edge of a road or near water have done substantially better with new growth and survivability. This follows because sucking insects do not get as much nourishment when living on plants with an abundant water supply. In our observations of infested stands, the surviving trees with access to the most water in the plots are the ones that are the healthiest, although the amount of foliage left on these surviving trees is still substantially less than what would be present in uninfested stands. The more xeric sites at the top of ridges and the sites where the hemlock is growing in marginal conditions are the sites where the heaviest mortality is found in NJ.

The effects of environmental conditions on new growth can be complex and not always as predicable as might be expected. In 2001, 9 of 11 plots experienced increases in new growth, which was duplicated in 2002 when 8 of 11 plots experienced increases while HWA levels remained relatively stable. The increase in new growth in 2001 normally would be expected to cause a corresponding increase in HWA population in 2002, which in turn would

**Table 1. Percent New Growth of Live Trees and HWA Population Level in the Plots by Year.**
Numbers indicate the percent new growth and the letters indicate the HWA population, L = low < 30 adelgids/100 needles, H = high > 30 adelgids/100 needles, N = none

| PLOT/YEAR | 1988 | 1991 | 1993 | 1995 | 1997 | 1999 | 2001 | 2002 |
|---|---|---|---|---|---|---|---|---|
| **A. Hewitt S.F.** | - | 87 | 23 | 80 | 63.6 | 1.5 | 59.5 | 71.8 |
| HWA pop'n. | - | L | L | L | H | H | L | L |
| **Clinton Res.** | 65 | 91 | 54 | 87 | 56 | 25.7 | 55.3 | 68.5 |
| HWA pop'n. | N | L | N | L | L | L | L | L |
| **High Point S.P.** | 53 | 89 | 58 | 59 | 57.2 | 38.2 | 46.5 | 65.9 |
| HWA pop'n. | N | L | L | L | L | H | L | H |
| **Johnson Lake** | 58 | 9.4 | 12 | 69 | 57.5 | 4.3 | 62.8 | 69.8 |
| | - | - | - | - | - | - | (42) | (45.7) |
| HWA pop'n. | L | H | L | H | H | H | H | H |
| **Lake Valhalla** | 65 | 47 | 28 | 78 | 40.9 | 6.8 | 50.4 | 33 |
| HWA pop'n. | L | H | L | H | H | H | H | L |
| **Millbrook Village** | 55.1 | 73.2 | 11.0 | 66.8 | 66.1 | 2.1 | 32.7 | 64.8 |
| HWA pop'n. | L | H | H | L | L | H | L | x |
| **Schooley's Mt.** | 5.5 | 58.6 | 43.8 | 80.4 | 49.7 | 14.3 | 55.1 | 74.1 |
| HWA pop'n. | H | L | L | H | H | H | H | L |
| **Shades of Death** | 6.1 | 44.9 | 5.9 | 74.1 | 80.9 | 7 | 47.6 | 21.5 |
| | - | - | - | - | - | - | (15.9) | (7.2) |
| HWA pop'n. | H | L | L | L | H | H | L | H |
| **Tillman's Ravine** | - | 89.0 | 76.7 | 62.9 | 62.7 | 32.2 | 34.7 | 62.9 |
| HWA pop'n. | - | N | N | N | L | L | L | L |
| **Walnridge** | 76.4 | - | 45.6 | 40.2 | 82.2 | 6.2 | 75.1 | 38.8 |
| HWA pop'n. | L | - | L | H | L | H | H | H |
| **Worthington S.F.** | 6.9 | 52.6 | 24.7 | 64.1 | 79.5 | 5.7 | 30 | 78.3 |
| | - | - | - | - | - | - | (18.7) | (52.2) |
| HWA pop'n. | H | L | H | H | H | H | H | L |

X = Field personnel did not receive the required permits to remove cuttings from this site in 2002.
( ) = Figure in ( ) is the % of new growth of all trees (including dead ones) in the plot. Figures without ( ) are the % new growth of just the live trees in the plot.

have a more negative impact on new growth, but that did not happen. Conditions causing moisture stress can have an adverse affect on HWA population levels. The drought condition NJ experienced during the summer of 2002 probably had such an effect on the HWA population. That and the subsequent cool, wet spring in 2002, which provided favorable growing conditions for the hemlocks probably accounted for the increases in new growth in the hemlock plots. Low temperatures can result in decreased survivability of overwintering HWA. Field personnel have observed a higher mortality of HWA following periods of extreme low temperatures then following periods of average normal winter temperatures. NJ endured such a prolonged period of low temperatures in January of 2003, which may have an adverse affect on the HWA population. This could result in even more new growth in 2003.

## Crown Ratings

Table 1 showed the population level of the HWA in the plots over the course of the project while Table 2 shows the crown ratings for each of the plots in 1994 and 2002**.** The plots that have a series of years where the HWA population was heavy are the plots that have the lowest crown ratios, lowest crown densities and the highest transparencies. Taken all together, the relative health of the hemlock in these plots (Shades of Death, Schooley's Mountain, Johnson Lake, Lake Valhalla and Worthington State Forest) is poor when compared to lightly infested stands (High Point, Tillman's Ravine and Clinton Reservoir) where the trees are still somewhat healthy. The stands that have been attacked earliest by the HWA are the stands that are in the poorest health in New Jersey.

**Table 2. Average Crown Ratings for all Plots in 1994 & 2002.**

| Plot/year | | Ratio | Trans | Dens. | Plot/year | | Ratio | Trans | Dens. |
|---|---|---|---|---|---|---|---|---|---|
| Hewitt S.F. | 94 | 80.5 | 31.1 | 38.7 | Schooleys Mt | 94 | 53.8 | 57.3 | 25.4 |
| | 02 | 45.5 | 84.5 | 14.5 | | 02 | 14.5 | 90.5 | 7.3 |
| Clinton | 94 | 53.8 | 10.9 | 51.5 | Tillman's Ravine | 94 | 77.4 | 16.6 | 51.6 |
| | 02 | 54.6* | 40.5* | 36.0* | | 02 | 73.7 | 68.7 | 28.4 |
| | 02 | 35.8** | 75.0** | 23.6** | | | | | |
| High Point | 94 | 75.4 | 15.7 | 47.9 | Lk. Valhalla | 94 | 72.7 | 42.5 | 34.0 |
| | 02 | 50.2 # | 68.8# | 33.1# | | 02 | 24.3 | 85.2 | 16.2 |
| Johnson Lk. | 94 | 53.8 | 57.3 | 25.4 | Walnridge | 94 | 38.2 | 43.4 | 38.6 |
| | 02 | 2.8 | 98.0 | 2.2 | | 02 | X | X | X |
| Millbrook | 94 | 73.7 | 25.3 | 45.3 | Worthington | 94 | 50.7 | 36.7 | 28.3 |
| | 02 | 57.8 | 62.8 | 34.0 | | 02 | 16.8 | 85.0 | 13.2 |
| Shades Dth. | 94 | 37.7 | 11.1 | 40.0 | | | | | |
| | 02 | 0.9 | 98.5 | 2.1 | | | | | |

*** =** Trees that were dead in 2001 & 2002 as a result of drought and *Fiorinia* scale were not used when compiling the averages.
**** =** All trees, including those that were dead from drought and *Fiorina* scale were used when compiling the averages.
**#** = Trees that were dead in 2001 & 2002 as a result of beaver activity (girdling or drowning from pond formation) were not used when compiling the averages.
X = Field personnel were not able to perform a crown rating survey at this site in 2002.

The most stressed trees have low crown ratings for density and high crown ratings for transparency. The crown ratings in a hemlock stand decline after the HWA population in that stand increases. The effect is not seen for a few years but when the initial data from each stand is compared to the data from some years later the effect is readily apparent.

**Tree Mortality Considerations**

Obviously the HWA is putting stress on the trees in the forest. Table 3 shows the stand mortality with the greatest mortality occurring in the stands that were heavily infested with the HWA for the longest period of time. These are also the stands that have the weakest overall crown ratings. The trend is disturbing in that where the HWA populations have been the heaviest; the tree mortality is the highest

There was very little change in mortality in 2002 as compared to 2001. Table 3 shows the mortality of the marked plot trees as a percent. Again the data are consistent in that the plots that have had heavy populations of HWA the longest are the ones that have the highest mortality. The mortality sometimes does not appear until the second round of heavy HWA infestation but it can appear in as little as three years.

**Table 3. Mortality of the Plot Trees in Percent by Year**

| Plot | 89 | 91 | 93 | 95 | 97 | 99 | 01 | 02 |
|---|---|---|---|---|---|---|---|---|
| A. Hewitt SF | 0.0 | 0.0 | 0.0 | 0.0 | 5.3 | 15.8 | 21.1 | 31.6 |
| Clinton Res | 0.0 | 0.0 | 0.0 | 0.0 | 3.4 | 3.4 | 34.5* | 34.5* |
| High Point SP | 0.0 | 0.0 | 9.1 | 12.1 | 12.1 | 15.2 | 29.2** | 29.2** |
| Johnson Lake | 0.0 | 0.0 | 8.0 | 48.0 | 68.0 | 76.0 | 92.0 | 92.0 |
| Lake Valhalla | 0.0 | 0.0 | 0.0 | 4.8 | 4.8 | 9.5 | 38.1 | 52.4 |
| Millbrook | 0.0 | 0.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Schooley’s Mt. | 0.0 | 0.0 | 15.0 | 25.0 | 40.0 | 50.0 | 65.0 | 70.0 |
| Shades of Death | 0.0 | 3.8 | 19.2 | 65.4 | 73.1 | 73.1 | 96.2 | 96.2 |
| Tillman’s Ravine | 0.0 | 0.0 | 0.0 | 0.0 | 5.3 | 5.3 | 5.3 | 5.3 |
| Walnridge | 3.8 | 3.8 | 7.7 | 15.4 | 46.2 | 53.8 | 57.7 | *** |
| Worthington SF | 0.0 | 0.0 | 12.0 | 16.0 | 40.0 | 40.0 | 56.0 | 56.0 |

* = Mortality here is due to drought and *Fiorinia* scale because hemlock woolly adelgid populations are low.
**** =** Trees that were dead in 2001 & 2002 as a result of beaver activity (girdling or drowning from pond formation) were not used when compiling the average.
*** = Field personnel were not able to perform a mortality survey at this site in 2002.

Lake Valhalla had a considerable increase in mortality in 2002. The trees at this plot have been stressed for the past several years and the health of the stand has been declining as demonstrated by the continuing decrease in crown ratings of density and ratio while transparency increased (Table 2). The inability to withstand the effects of the drought condition experienced in 2002 along with the continued high HWA population is probably the cause of the increased mortality there. The slight increase in mortality at A. Hewitt State Forest was probably due to the drought as well since the HWA population at that plot continues to be low. The plot at Hewitt is one of the more xeric sites at the top of a ridge.

From the data presented here there is no hard and fast rule as to when substantial hemlock mortality may occur in an affected stand. The mortality did not occur as quickly as expected when the HWA first came into the state but it eventually occurred and is present at high rates in stands where the HWA population was initially the heaviest. There are probably other factors that contribute to the death of the trees but the one factor that stands out consistently is the presence of a heavy HWA population. *Fiorinia externa* (Homoptera: Diaspididae) is present in many of the stands and is also a stressor but its effect on the stands is not altogether clear. Hemlock mortality does seem to be affected by the amount of water available to the trees and the amount of water available is related to the percent new growth. From observation in the heavily infested stands monitored in N.J., the closer a tree is to a water source, the healthier it appears. At Shades of Death, Walnridge, Schooley's Mountain, Lake Valhalla and Johnson Lake, the trees that are still alive and the healthiest are at the bottom of a slope, near a stream, or by a roadside which is at the bottom of a slope. In addition, Shades of Death, Schooley's Mountain, Lake Valhalla and Johnson Lake were the plots with the highest mortality and they were all plots where the hemlocks are on a ridge or a site that is somewhat xeric. They were also the plots that have had high HWA populations in the past. It seems that if a site has been heavily infested, the surviving trees are the ones that have the best access to a water supply. The presence of a water source or perhaps high soil moisture then, may affect the ability of a hemlock tree to survive stressors like the HWA. It must be stressed though that even the trees close to water in heavily infested stands are still stressed by the HWA. The water may be just giving them a little extra time. Abundant water negatively affects sucking insect populations and it seems reasonable to infer that it negatively impacts the HWA as well.

Figure 2 shows a healthy hemlock stand with no adelgid, as does Figure 3. These stands are well shaded, with

**Figure 2. Healthy hemlock in New Jersey**

**Figure 3. Typical dark hemlock stand**

an understory of young hemlock. Figure 4 shows mortality as it first appears in a stand attacked by the HWA. Figure 5 illustrates the hemlock stand after mortality has been present for a few years. There is little understory and many branches have fallen onto the ground. Widowmakers are a common sight and many of the trees have split and fallen.

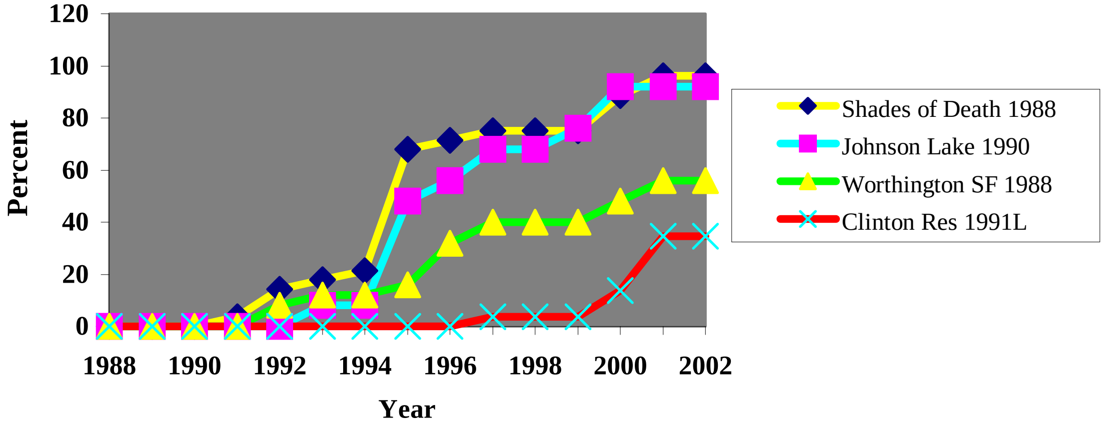
**Figure 4. Initial mortality at Sparta Glen.**

**Figure 5. Stand mortality at Johnson Lake.**

There was no concurrent mortality of other tree species in any of the stands. Mortality shows up about 3- 4 years after the first heavy HWA infestation and does increase in succeeding years but there is no gradual increase in mortality from year to year. The HWA population declines as the trees become a poor food source; there is less new growth as the HWA population declines and the trees recover but as the amount of new growth increases, the HWA population increases once again and the trees decline further. Figure 6 shows four plots and the year that they were first heavily infested in the inset. Clinton Reservoir was lightly infested in 1991 and has yet to be heavily infested. The trend in all of the plots is for mortality to increase.

The mortality increase seen at Clinton Reservoir in 2001 and 2002 was due to drought and *Fiorinia* scale because hemlock woolly adelgid populations are low.

**Figure 6. Cumulative % Mortality in 4 Plots 1988 - 2002**




**CONCLUSION**

From the results presented here, it appears that the HWA continues to be negatively impacting hemlock stands in New Jersey and mortality in the most heavily infested stands is increasing. The longer that a stand has been heavily infested, the greater the mortality. Other environmental factors are involved such as water supply, but the one factor that is consistent across the stands where the mortality is the greatest is a heavy population of HWA. The crown ratings of density, and ratio decreased in heavily infested stands while the transparency increased. Eight of the 11 test sites experienced increased new growth rates in 2002 while only two sites had a corresponding increase in HWA population. That combined with an above average amount of precipitation in the fall of 2002, which should further increase new growth in the spring, will probably result in an increased HWA population in 2003 if past trends hold true to form. Should this happen, decreased amounts of new growth can be expected in 2003 due to the anticipated increase in HWA population. NJ has experienced a prolonged period of low temperatures in January of 2003, however, which may have an adverse affect on the HWA population. If that occurs, it could result in even more new growth in 2003, which would greatly benefit the health of the hemlock stands in NJ.

**Photo credits:**

Figure 1,2. – Jason Zhang and James Lashomb, Department of Entomology, Rutgers University, Cook College
Figures 3, 4 – Robert Ward, NJDA PABIL
Figures 5 – Lauren Bronhard, NJDA PABIL

**REFERENCES**

Onken, B.P. 1994. A summary of impacts from HWA and drought on eastern hemlocks in New Jersey. USDA-FS, Morgantown, WV. Unpublished, from data provided by the New Jersey Department of Agriculture, Division of Plant Industry, Phillip Alampi Beneficial Insect Laboratory.

McClure, M. S., S. M. Salom, and K.S. Shields. 1996. Hemlock Woolly Adelgid. Forest Health Technology Enterprise Team, USDA-FS, Morgantown, WV. FHTET-96-35.

Millers, I., R. Anderson, W. Burkman, W. Hoffard. 1992. Crown Condition Rating Guide. USDA-FS Technical Report.

Ward, R., M. Mayer and R.C. Chianese. 1992. The effect of the hemlock woolly adelgid *Adelges tsugae* (Homoptera: Adelgidae) in New Jersey forests. Unpublished Annual Report, Phillip Alampi Beneficial Insect Laboratory, Division of Plant Industry, New Jersey Department of Agriculture.

Internet 1. 1997. http://climate.rutgers.edu/stateclim/njhistprecip.html